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TITLE: FIRST QUARTERLY REPORT OF STUDY OF CAPACITORS FOR STATIC INVERTERS AND CONVERTERS, Aug. 16 - Nov. 16 - 1963

(AUGUST 16, 1963 - NOVEMBER 16, 1963)

CONTRACT NO: (NASA **NAS3-2788**)

PREPARED FOR THE

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By J. F. Scoville 1963 15p refs

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TECHNICAL MANAGEMENT
NASA-LEWIS RESEARCH CENTER
AUXILIARY POWER GENERATION OFFICE
FRANCIS GOURASH

PREPARED FOR THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

By J. F. Scoville

GENERAL ELECTRIC

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SUMMARY

15878 author

On August 16, 1963, a "Study of Capacitors for Static Inverters and Converters" was started. Its objective is to facilitate proper capacitor selection to minimize size and weight consistent with over-all equipment performance and reliability. The need for such a study was influenced by the significant capacitor volume, weight and reliability factors in static inverters and converters, particularly in space environments where volume, weight and reliability are at a premium.

General Electric's Specialty Control Department in Waynesboro, Virginia is conducting this capacitor study.

The first quarterly report covers the work accomplished from August 16 to November 16, 1963 on the capacitor study. This report contains:

a) An analysis of the operation of commutating capacitors.

b) Selection of capacitance values to conduct a state-of-the-art survey.

c) Engineering specifications for capacitors for the survey. Ad7H0R

INTRODUCTION

A need for the "Study of Capacitors for Static Inverters and Converters" was influenced by the stringent requirements imposed on capacitors by the operating nature of the equipment and environment. These stringent requirements may be divided into two general catagories: (1) Heat generation; and (2) Heat transfer.

In static inverters, appreciable heat generation within capacitors is caused by input voltage ripple having frequencies of several kilocycles, commutating current pulses of approximately 5 kilocycles and harmonic currents in the output. Heat transfer from the capacitors is generally limited to conduction across the mounting surface to radiator systems on space vehicles.

Lack of adequate alternating current data and characteristics of electrolytic, paper and film dielectric capacitors contribute to the difficulty of properly applying capacitors to aerospace inverters and converters. Improper application of capacitors in aerospace static inverter equipment could result in appreciable penalties in weight and reliability factors, both of which are at a premium in equipments operating in space environments.

Objectives of this study are to: (1) establish capacitor characteristics, ratings and limits for such factors as safe operating voltage, temperature rise, power factor and reliability in aerospace static inverter and converter applications, and (2) facilitate proper capacitor selection to minimize volume and weight consistent with maximum equipment performance and reliability.

Capacitors to be studied are limited to those suitable for use in aerospace static inverters and converters operating in a space environment. These inverters are to provide 400 cycle, 3 phase outputs at voltage levels of 115/200 volts in power output ranges from 100 watts to 10 kilowatts. Input voltages will range from 25 to 105 volts dc.

The capacitor study consists of the following phases:

Phase I -- Define Capacitor State-of-the-Art Survey -- Analyzing operation of commutating and filter capacitors and determining characteristics. (August 16 to October 1, 1963)

Phase II -- Conduct Capacitor State-of-the-Art Survey -- Requesting proposals from all known capacitor vendors for selected representative capacitor type and rating specifications. (October 1, 1963 to January 1, 1964)

Phase III -- Experimental Testing -- Obtaining test units and applying capacitor operational test parameters to determine affects of power factor, thermal conditions, current waveforms and safe voltage levels on volume, weight and reliability. (January 1 to July 1, 1964)

Phase IV -- Capacitor Evaluation and Recommendations -- Evaluting state-of-the-art capacitor performance in static inverter and converter applications and recommendations for new approaches or development to improve the state-of-the-art. (July 1 to August 15, 1961)

This is the first quarterly report of the work accomplished from August 16 to November 16, 1963. During this time period, Phase I was completed and Phase II was initiated.

1.0 Capacitor Types and Basic Considerations

1.1 Types and Functions

Static inverters that employ silicon controlled rectifiers for static switches generally require three (3) types of capacitors: (1) Commutating; (2) A.C. Filter; and (3) D.C. Filter. Static inverters that employ transistors for static switches generally require only two (2) types of capacitors: (1) A.C. Filter, and (2) D.C. Filter.

Commutating capacitors in conjunction with commutating reactors are used for electrical energy storage to effect commutation of load current from one silicon controlled rectifier to another. The stored electrical energy in these commutating components furnish sufficient back biasing voltage to a rectifier that has been conducting to turn it off when a second rectifier is turned on. The analysis contained in Appendix A explains this functional operation in more detail.

Alternating current filter capacitors are normally required with reactors in the output circuits of static inverters to shape voltage and current waveforms from quasi square-wave, caused by the alternate static switching, to sinusoidal waveforms. Generally, these inductive-capacitive (L-C) filters employ capacitors connected in series and in parallel with the load as shown in Figure 1.

Direct current filter capacitors are usually employed in input circuits of static inverters and output circuits of converters. Their main purpose is storage of electrical energy and release thereof for reducing or regulating source voltage variations from pulse loading.

2.0 Application Considerations

2.1 Environments

Potential environments that capacitors may encounter in aerospace static inverter and converter applications are major considerations in the selection of capacitor materials. Environmental conditions, assumed to be representative for a variety of equipment design applications, selected for a state-of-the-art survey in this study are:

A) Heat Sink Ambient Temperature Range: -55°C to +85°C.

B) Capacitor heat transfer by conduction to heat sink.

C) Shocks of 35 g's in half sine wave shocks for 0.008 seconds.

D) Vibration: Sinusoidal

Frequency (CPS)	Force or Displacement
5-20	0.3 inches double amplitude
20-100	5 g's
100-500	10 g's
500-2000	15 g's

E) Radiation:

5×10^{-12} NVT Fast Neutrons/cm^2

5×10^{-7} RADS (carbon) Gamma Particles

F) Hermetically sealed construction to protect capacitor from effects of sublimation from temperature-pressure conditions.

Use of these environment considerations, in the capacitor state-of-the-art survey is being made to facilitate the usefulness of this study to equipment designers of aerospace static inverters and converters.

2.2 Power Source

Types of power sources considered for the inverters and converters in this study are: a) Batteries, b) Solar cells, c) Thermionic converters, d) Fuel cells, and e) Rotating d.c. generators.

Power source characteristics, particularly voltage regulation, ripple and transient voltages are important considerations in selection of capacitors for equipment designs.

Source voltage range for this capacitor study is from 25 to 105 volts d.c. However, with present and near future power sources it appears that source voltage ranges from 25 to 35 volts, 50 to 65 volts and 90 to 105 volts offer a representative coverage within the range from 25 to 105 volts. These three (3) discrete source voltage ranges were selected for the capacitor state-of-the-art survey.

The second power source consideration is ripple. A peak-to-peak ripple of plus and minus 10 per cent of the maximum steady state voltage was chosen as being representative for various applications of d.c. input filter capacitors. Maximum frequency of the ripple voltage was selected at 25 kilocycles. This frequency is considered representative of other unfiltered static inverter equipment operating from the same power source.

The third power source consideration is voltage transients. Removal of loads near the end of a transmission line can cause transient overvoltage conditions. For this study, transient overvoltages of 150 per cent for durations up to 100 milliseconds are considered representative for some aerospace static inverter applications of d.c. filter capacitors.

2.3 Load

Load characteristics, such as transient overvoltage from load removal and overcurrents are also important considerations in the selection of a.c. filter capacitors for equipment designs. Transient overvoltage of 125 per cent of rated voltage for a duration of 5 cycles of the rated 400 cycle base was chosen to be representative of equipment applications for this study. Overcurrents of twice-rated load current for 5 seconds was also considered representative of equipment applications for this study. However, output inductive-capacitive (L-C) filter configurations and power factor of the load during overcurrent conditions have a relationship to the peak currents and voltages of the capacitors. For purposes of this study, two (2) rated rms voltage values were selected for the capacitor survey. These are 135 and 270 volts rms, 420 cycles. Dielectric voltage rating for these capacitors were chosen to be 600 and 1000 volts respectively to accommodate peak transient voltage conditions. The 420 cycle rating was chosen to provide adequate margin from overheating during inverter operation at 400 $\pm$ 20 cps.

3.0 State-of-the-Art-Survey

3.1 Purpose

Conduction of a capacitor survey with specific capacitor ratings and duty will facilitate establishment of a state-of-the-art base from which capacitors can be evaluated. Also, contacts with all known capacitor vendors will enable selection of capacitors for testing that are representative of the state-of-the-art.

3.2 Evaluation Criteria

Establishing the state-of-the-art, of specific capacitor ratings and duty for application in static inverters and converters operating in space environments, is planned to be accomplished with the following criteria:

A) Volume to capacitance ratio
B) Weight to capacitance ratio
C) Power factor to thermal resistance ratio
D) Volume-weight to volt-ampere rating or energy storage ratio
E) Cost to volt ampere rating or energy storage ratio

These criteria can only be applied logically when capacitors are compared to a common base. Therefore, engineering specifications for capacitor types were prepared with which to conduct the survey. These specifications, based on analysis of circuit operation and design experience with similar circuits, are in Appendix B of this report.

3.3 Selected Capacitor Values

Static inverter and converter output power range of 100 watts to 10 kilowatts used in this study is subdivided into these three (3) output power ranges and output power level selected for capacitor sizing:

Output Power Range (watts)	Output Power Level for Capacitor Sizing (watts)
100-500	300
500-2,000	1250
2,000-10,000	5,000

3.3.1 Commutating Capacitors

Analysis of the operation of commutating capacitors and design experience with static inverters has shown that a relationship exists between the value of capacitor and characteristics of the static switching device. The characteristics of the switching device that enter this relationship to capacitor value are magnitude of load current flowing through the switching device at the end of each half cycle (i.e., start of commutation) and device turn-off switching time.

Four (4) types of silicon controlled rectifiers, with current ratings that are capable of handling the inverter power output range in this study, were chosen for sizing the commutating capacitors. Turn-off times used for these silicon controlled rectifiers are either vendor guaranteed or test selected by vendor. Values of current flowing through the silicon controlled rectifiers at the end of the half cycle are based on design experience with these devices for 180 degree conduction angles.

The design equations used for sizing the commutating capacitors are:

$$C = \frac{5.22\, I_o\, t_{off}}{E_{min.}} \quad ; \qquad I_p = \frac{1.37\, I_o\, E_{max.}}{E_{min.}}$$

Where I_o is current flowing through the silicon controlled rectifier at the end of the half cycle, t_{off} is turn-off time for the rectifier, $E_{max.}$ and $E_{min.}$ are maximum and minimum steady state source voltages respectively and I_p is peak amperes capacitor current.

These equations are derived in Appendix A of this report.

Commutating capacitors, selected from the analysis shown in Appendix A for the state-of-the-art survey are:

Capacitance (ufd)	D. C. Voltages
5	35, 65 and 105
15	35, 65 and 105
50	35, 65 and 105

These capacitance values, when used singly or in multiples, are capable of covering the inverter output power range for this study.

3.3.2 A.C. Filter Capacitors

Inverter output voltage in this study is 115/200 volts, 400 cycles per second. Filter capacitors connected in parallel with the load, as shown in Figure 1, have voltage ratings consistent with the load voltage. Voltage ratings of filter capacitors connected in series with the load or reactors are dependent on inverter waveforms, filter design and load currents.

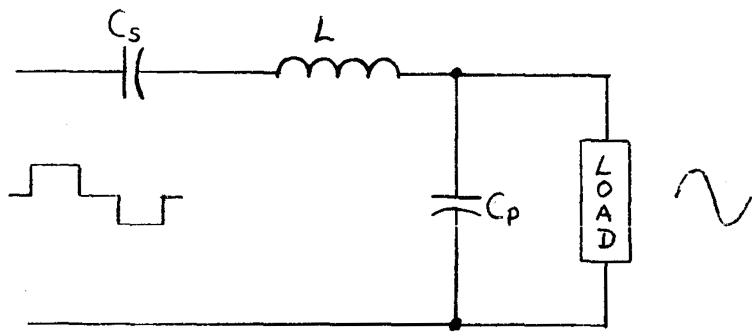


FIGURE 1

A.C. FILTER CONFIGURATION

C_s - Series Capacitor

C_p - Parallel Capacitor

For this study, the following capacitors have been selected for the survey:

Capacitance (ufd)	RMS Voltage
1-3	135 and 270
8-10	135 and 270
50-60	135 and 270

These capacitance values, used singly or in multiples will accommodate many equipment designs within the output power range of this study.

3.3.3 D. C. Filter Capacitors

Discrete source voltage levels, selected for this study and survey, establish voltage ratings of the input filter capacitors. Two (2) capacitance ranges were selected for the capacitor surveys. These are:

Capacitance (ufd)	Voltages
1000-1500	35, 65 and 105
10, 000-15, 000	35, 65 and 105

These capacitance values, or multiples thereof, will accommodate many equipment designs within the inverter and converter ratings for this study.

4.0 Work Planned for Next Quarterly Report Period

Completion of the capacitor state-of-the-art survey and purchase of capacitors for the experimental testing are planned to be completed by the end of the next quarterly report period.

The experimental testing will be divided into two (2) general catagories: (1) Thermal testing; and (2) Life testing. These tests will be conducted to evaluate parameters such as frequency, power factor, voltage and/or current, volume-weight configuration affecting thermal conditions and levels of voltage and temperature related to minimum volume-weight to capacitance ratios for safe and reliable application. Completion of detailed test plans and procedures is scheduled during the next quarterly report period.

5.0. CONCLUSIONS

1. Minimum commutating capacitor values are determined from the static switching device turn-off time, the source voltage levels and load currents in static inverters and converters.

2. Conducting a capacitor survey with specifications for discrete capacitor values will facilitate establishment of a state-of-the-art reference for capacitors applicable to static inverter and converter designs.

Acknowledgements

The contributions of Messrs. A. L. Wellford, III and P. D. Corey of General Electric's Specialty Control Department, in establishing from design experience operating current characteristics for the silicon controlled rectifiers that are used in the commutating capacitor analyses, is gratefully acknowledged.

References

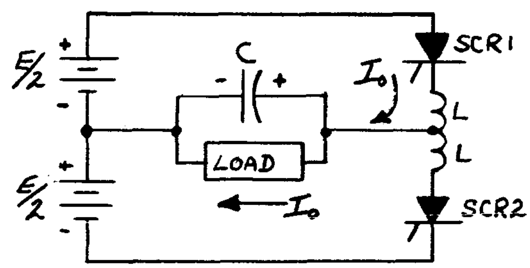
1. "General Electric Silicon Controlled Rectifier Manual", 2nd Edition, Edited by F. W. Gutzwiller, 1961.

APPENDIX A

Analyses for Determining Commutating Capacitors

Description of Operation

Half Bridge Circuit



C - Commutating Capacitor
L - Commutating Reactor
SCR - Silicon Controlled Rectifier

Figure A

Analysis of operation for this circuit is based on these assumptions:

1) Inductive load current does not change during the commutation interval.

2) Full load turn-off time is one half that at no load.

3) When capacitor voltage is zero, turn-off interval is over.

The equivalent circuit shown in Figure B is for the condition when SCR2 has just been triggered into conduction. and SCR1 conduction blocked at beginning of commutating interval.

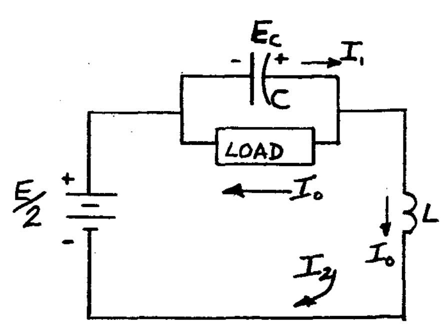


Figure B

Writing the voltage equation for the loop

$$\frac{E}{2}(t) + E_c(t) = \frac{1}{C}\int_0^t i_1(t)dt + L\frac{di_2(t)}{dt}$$ where t is turn-off interval

Equations describing the equivalent circuit, shown in Figure B, in Laplace notation are:

$$\frac{E}{2s} + \frac{E}{2s} + L\,I_o = \frac{I_1(s)}{sC} + I_2(s)\,sL \qquad (1)$$

$$I_2(s) = I_1(s) - \frac{I_o}{s} \qquad (2)$$

$$E_c(s) = \frac{E}{2s} - \frac{I_1(s)}{sC} \qquad (3)$$

Combining equation (1) and (2) gives

$$\frac{E}{s} + 2\,L\,I_o = I_1(s)\left(\frac{1}{sC} + sL\right)$$

$$I_1(s) = \frac{\frac{E}{s} + 2L\,I_o}{\frac{1}{sC} + sL} \qquad (4)$$

Substituting equation (4) into equation (3) gives

$$E_c(s) = \frac{E}{2s} - \frac{E}{s(1+LCs^2)} - \frac{2L\,I_o}{(1+LCs^2)}$$

$$\mathcal{L}^{-1}E_c(s) = E_c(t) = \frac{E}{2} - E(1-\cos wt) - 2L\,I_o w\sin wt \qquad (5)$$

where $w = \sqrt{\frac{1}{LC}}$

when $E_c = o$, turn-off interval is over. Solving for t

$$\frac{E}{2} = E\cos wt - 2\,L\,I_o\,w\sin wt \qquad (6)$$

At $I_o = o$ (no load or current that goes through zero at end of half cycle)

$E \cos wt = \frac{E}{2}$; $\cos wt = .5$; $wt = \pi/3$

$t = \pi/3w$

Using the second assumption that turn-off (t off) at full load is one half of t, $t\ off = \pi/6w = \frac{\pi\sqrt{LC}}{6}$

Using t off in equation (6) gives

$$\frac{E}{2} = E \cos \pi/6 - 2\ L\ I_o\ w \sin \pi/6$$

Substituting $1/\sqrt{LC}$ for w

$$\frac{E}{2} = \frac{E\sqrt{3}}{2} - \frac{L\ I_o}{\sqrt{LC}} = \frac{E\sqrt{3}}{2} - I_o\sqrt{\frac{L}{C}}$$

$$0.366\ E = I_o\sqrt{L/C} \qquad (7)$$

To determine the capacitance (c), divide equation (7) by t off, which gives

$$\frac{0.366E}{t\ off} = \frac{6\ I_o}{C}$$

$$C = \frac{5.22\ I_o\ t\ off}{E} \qquad (8)$$

Inductance value (L) may be determined by multiplying equation (7) by t off, which gives

$$L = \frac{0.7\ E\ t\ off}{I_o} \qquad (9)$$

E in equations (8) and (9) are minimum steady state source voltage and I_o is the load current to be commutated at the end of a half cycle.

Capacitance values for circuit configurations shown in Figure A are determined by the minimum steady state voltage levels, I_o and t off of silicon controlled rectifiers listed in Table I.

TABLE I

Silicon Controlled Rectifiers Type	I_o (amps)	t off (uses)	Minimum Source Voltage Levels 25V	50V C(μfds)	90V
G. E. C-11	6	12	15	7.5	4.2
G. E. C-40	16	12	40	20	11.1
G. E. C-55	60	20	250	125	69.0
G. E. C-80	120	25	625	313	174.0

Similar analyses for circuit configurations shown in Figures C and D will yield capacitance values equivalent to one half the values shown in Table I.

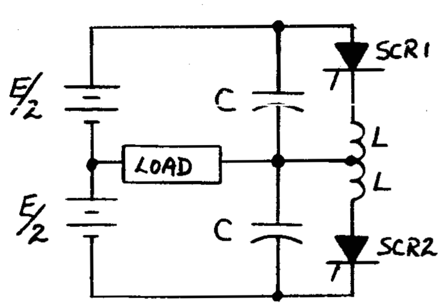


Figure C

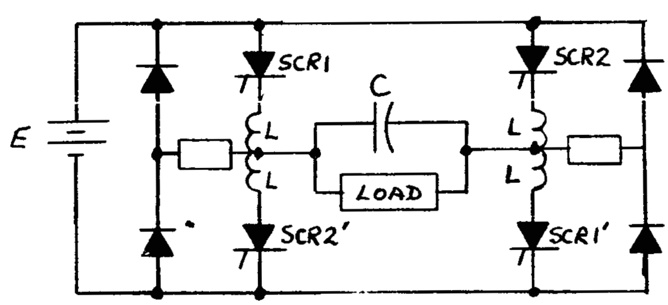


Figure D

Capacitance values, in parallel type inverter configurations, shown in Figure E, are equivalent to one fourth the values of C tabulated in Table I.

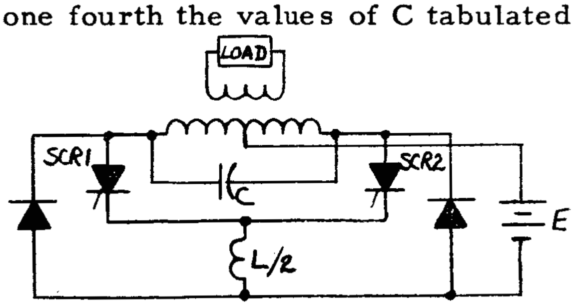


Figure E

Values of commutating capacitances selected for the capacitor study survey are 51, 15 and 50 microfarads. Selection of these values is based on the use of multiple series and parallel capacitor networks for half bridge, full bridge and parallel types of inverters and converters.

Peak recurring capacitor currents are determined as follows.

From energy storage equations

$$\frac{L\,I_p^2}{2} = \frac{E^2 C}{2}$$

$I_p = E\sqrt{C/L}$, where E is maximum steady state source voltage

Substituting C and L from equations (8) and (9)

$$I_p = 2.74\, I_o \frac{E\ max.}{E\ min.} \quad \text{for values of C} \qquad (10a)$$

$$I_p = 1.37\, I_o \frac{E\ max.}{E\ min.} \quad \text{for values of C/2} \qquad (10b)$$

Peak recurring capacitor currents for the selected capacitance values are determined from silicon controlled rectifier types, I_o and C values from Table I and are shown in Table II.

TABLE II

Rectifier Type	Voltage Level	Capacitance (ufd)	Capacitor Circuit Configuration	Ipk (amps)
C-11	25-35	15	C	23.1
C-40	50-65	10	C/2	28.5
C-80	90-105	50	C	109

ENGINEERING SPECIFICATIONS FOR COMMUTATING CAPACITORS

1. Scope--This specification is for an industry survey of capacitors for application in 115/200 volt, 3 phase, 400 cps output static inverters and converters in space environments. The criteria to be used in this survey are:

   A. Volume to capacitance ratio
   B. Weight to capacitance ratio
   C. Power factor to thermal resistance ratio
   D. Volume and weight to energy-storage ratio
   E. Cost to energy-storage ratio

2. Range of Capacitor Ratings

   A. 5 microfarads /20-10% over temperature range

	1	2	3
Peak Voltage	35	65	105
Peak Voltage (100msec. D.C. Voltage Transient	52	97	157
Peak Current Amperes @ D.C. Working Voltage	4.6	3.6	11
Peak Current and Voltage Waveforms	Fig. 1A	Fig. 1A	Fig. 1B
Peak Current Amperes (100 msec. D.C. Voltage Transient)	6.35	12.8	15.1

   B. 15 microfarads /20-10% over temperature range

	1	2	3
Peak Voltage	35	65	105
Peak Voltage (100 msec. D.C. Voltage Transient)	52	97	157
Peak Current Amperes @ D.C. Working Voltage	13.8	26	33
Peak Current and Voltage Waveforms	Fig. 1A	Fig. 1A	Fig. 1B
Peak Current Amperes (100msec. D.C. Voltage Transients)	20.5	38.4	49.3

C. 50 microfarads ≠20-10% over temperature range

	1	2	3
Peak Voltage	35	65	105
Peak Voltage (100 msec. D.C. Voltage Transient)	52	97	157
Peak Current Ampere @D.C. Working Voltage	46	86	110
Peak Current and Voltage Waveforms	Fig. 1A	Fig.1A	Fig. 1B
Peak Current Amperes (100 msec. D.C. Voltage Transient)	68	129	165.0

3. Physical Size and Weight--Vendor to recommend optimum size and weight for proposed capacitance value and voltage rating.

4. Ambient Temperature-- -55 to ≠85°C heat sink ambient with a maximum of 125°C capacitor hot spot temperature.

5. Method of Capacitor Power Loss Transfer--Conduction through mounting surface to heat sink ambient.

6. Construction--Hermetically sealed. Capacitor to be subjected to 0.25 atmosphere within equipment enclosure during operational life.

7. Shock--Capacitor is to withstand three 35 g shocks in each direction along the major axes. The applied shocks are half sine waves of 0.008 second duration.

8. Vibration--While energized, capacitor is to withstand the following sinusoidal vibration requirements:

Frequency	Force or Displacement
5-20	0.3 inches D.A.
20-100	5 g's
100-500	10 g's
500-2000	15 g's

Duration of the applied vibrational forces is four 15-minute logrithmic sweeps from 5-2000-5 cps at the specified levels and 10-minute dwells at each resonant frequency found during the sweeps.

9. <u>Radiation</u>--Capacitor shall have a tolerance to the following integrated radiation dosage without malfunction:

   A. 5×10^{12} NVT Fast Neutrons/cm^2

   B. 5×10^{7} RADS (Carbon) Gamma Rays

10. <u>Operational Life Objective</u>--Energized for 3 years continuously while exposed to the radiation listed in 9 above and 85°C heat sink temperature. Capacitor to remain within capacitance tolerance.

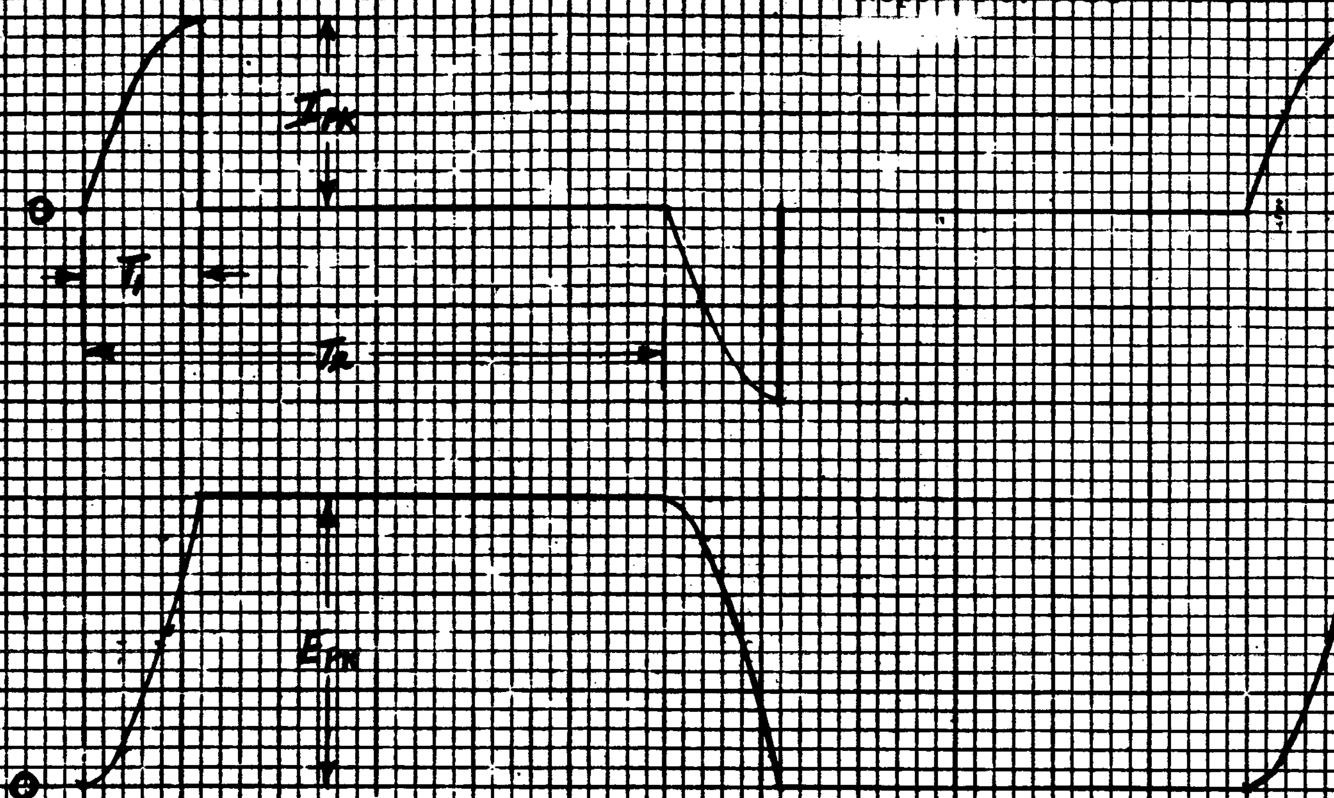


FIGURE 1

PEAK CURRENT AND VOLTAGE WAVEFORMS

FIGURE 1-A T_1 = 74.5 microseconds
T_2 = 1256 microseconds
FIGURE 1-B T_1 = 74.5 microseconds
T_2 = 1256 microseconds

APPENDIX B

ENGINEERING SPECIFICATIONS FOR D.C. FILTER CAPACITORS

1. Scope--This specification is for an industry survey of capacitors for application in 115/200 volt, 3 phase, 400 cps output static inverters and converters operating in space environments. The criteria to be used in this survey are:

   A. Volume to capacitance ratio
   B. Weight to capacitance ratio
   C. Power factor to thermal resistance ratio
   D. Volume and weight to energy storage ratio
   E. Cost to energy storage ratio

   Vendor proposal of types (i.e., dielectric) is not limited to one.

2. Range of Capacitor Rating

   A. 1000-1500 microfarads $\pm$20% over temperature range

	1	2	3
D.C. Working Voltage	35	65	105
Surge Voltage for 100 msec.	52	97	157
P-P Ripple Voltage @ 25KC Rep Rate 2.5 KC	3.5	6.5	10.5

   B. 10,000-15,000microfarads $\pm$20% over temperature range

	1	2	3
D.C. Working Voltage	35	65	105
Surge Voltage for 100 msec.	52	97	157
P-P Ripple Voltage @ 25 KC, Rep Rate 2.5 KC	3.5	6.5	10.5

3. Phisical Size and Weight--Vendor to recommend optimum size and wieght for proposed capacitance value and voltage rating.

4. Ambient Temperature-- -55 to +85°C heat sink ambient with a maximum of 125°C capacitor hot spot temperature.

5. Method of Capacitor Power Loss Transfer--Conduction through mounting surface to heat sink ambient.

6. Construction--Hermetically sealed. Capacitor to be subjected to 0.25 atmosphere within equipment enclosure during operational life.

7. Shock--Capacitor is to withstand three 35 g shocks in each direction along the major axes. The applied shocks are half sine waves of 0.008 second duration.

8. Vibration--While energized, capacitor is to withstand the following sinusoidal vibration requirements:

Frequency	Force or Displacement
5-20	0.3 inches D.A.
20-100	5 g's
100-500	10 g's
500-2000	15 g's

Duration of the applied vibrational forces is four 15-minute logrithmic sweeps from 5-2000-5 cps at the specified levels and 10-minute dwells at each resonant frequency found during the sweeps.

9. Radiation--Capacitor shall have a tolerance to the following integrated radiation dosage without malfunction:

   A. 5×10^{12} NVT Fast Neutrons/cm^2

   B. 5×10^{7} RADS (Carbon) Gamma Rays

10. Operational Life Objective--Energized for 3 years continuously while exposed to the radiation listed in 9 above and 85°C heat sink temperature. Capacitor to remain within capacitance tolerance.

ENGINEERING SPECIFICATIONS FOR A.C. FILTER CAPACITORS

1. Scope--This specification is for an industry survey of capacitors for application in 115/200 volt, 3 phase, 400 cps output static inverters and converters in space environments. The criteria to be used in this survey are:

   A. Volume to capacitance ratio
   B. Weight to capacitance ratio
   C. Power factor to thermal resistance ratio
   D. Volume and weight to volt-ampere rating ratio
   E. Cost to volt-ampere rating ratio

   Vendor proposal of types (i.e., dielectric) is not limited to one.

2. Range of Capacitor Ratings

   A. 1-3 microfarads ±20% over temperature range.

	1	2
Voltage rms, 420 cps (rated)	135	270
Surge Voltage rms, 420 cps for 5 cycles	170	340
Rated Amperes rms	.355-1.065	.71-2.14
D.C. Voltage Dielectric Rating	600	1000

   B. 8-10 microfarads ±20% over temperature range

	1	2
Voltage rms, 420 cps (rated)	135	270
Surge Voltage rms, 420 cps for 5 cycles	170	340
Rated Amperes rms	2.85-3.55	5.69-7.1
D.C. Voltage Dielectric Rating	600	1000

C. 50-60 microfarads $\pm$20% over temperature range

	1	2
Voltage rms, 420 cps (rated)	135	270
Surge Voltage rms, 420 cps for 5 cycles	170	340
Rated Amperes rms	17.8-21.4	35.5-42.6
D. C. Voltage Dielectric Rating	600	1000

3. Physical Size and Weight--Vendor to recommend optimum size and weight for proposed capacitance value and voltage rating.

4. Ambient Temperature-- -55 to $+85^{\circ}$C heat sink ambient with a maximum of 125°C capacitor hot spot temperature.

5. Method of Capacitor Power Loss Transfer--Conduction through mounting surface to heat sink ambient.

6. Construction--Hermetically sealed. Capacitor to be subjected to 0.25 atmosphere within equipment enclosure during operational life.

7. Shock--Capacitor is to withstand three 35 g shocks in each direction along the major axes. The applied shocks are half sine waves of 0.008 second duration.

8. Vibration--While energized, capacitor is to withstand the following sinusoidal vibration requirements:

Frequency	Force or Displacement
5-20	0.3 inches D. A.
20-100	5 g's
100-500	10 g's
500-2000	15 g's

Duration of the applied vibrational forces is four 15-minute logrithmic sweeps from 5-2000-5 cps at the specified levels and 10-minute dwells at each resonant frequency found during the sweeps.

9. Radiation--Capacitor shall have a tolerance to the following integrated radiation dosage without malfunction:

   A. 5×10^{12} NVT Fast Neutrons/cm^2

   B. 5×10^{7} RADS (Carbon) Gamma Rays

10. Operational Life Objective--Energized for 3 years continuously while exposed to the radiation listed in 9 above and 85^{o}C heat sink temperature. Capacitor to remain within capacitance tolerance.

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